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The Effect of Industry Structure and Yardstick Design on Strategic Behavior with Yardstick Competition: an Experimental Study*

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Abstract

We present an experiment on yardstick competition. Experimental firms set cost levels in each period and can communicate with each other in an attempt to increase the regulated price. We find that when market shares are heterogeneous, collusion is least frequent and prices are lowest. The number of players on a market also influences prices, but to a lesser extent. Comparing across yardsticks, the discriminatory yardstick yields the lowest prices, while a best-practice yardstick yields the highest prices.

JEL Classification Codes: C73, C92, L13, L41.

Keywords: Collusion, Experiment, Regulation, Yardstick Competition, Asymmetries.

1 Introduction

Many network industries are subject to regulatory supervision as the subadditivity of costs makes them natural monopolies. In several cases, this regulation takes the form of yardstick competition, where the (maximum) price a firm is allowed to charge is determined by some function of the actual costs of all firms in the industry. Yet, an important question is to what extent such yardstick competition is prone to collusion,

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i.e. to what extent it induces firms to coordinate their individual costs, either tacitly or explicitly. This question becomes increasingly relevant if mergers in such an industry lead to fewer firms, and/or to firms that are more alike in terms of size. Such an institutional change has occurred, for example, in the Dutch energy distribution industry. In this industry, which is subject to yardstick regulation, the number of firms has declined from about 15 to about 7 during the past decade, while the remaining firms are highly unequal in scale (NMa, 2010).

In this paper, we address this issue. We study to what extent the number and size distribution of firms in a network industry with yardstick regulation facilitates collusion. We also study to what extent, for a given industry configuration, the extent of collusion is affected by the design of the yardstick. These are issues that are hard to tackle either empirically or theoretically. Empirically, it is hard to assess to what extent certain industry configurations are prone to collusion: first, as collusion is by its very essence hard to observe and second, because of a limited number of observations on the effects of yardstick regulation. Theoretically, it is hard to do so as well: first, as repeated game models are plagued by a multiplicity of equilibria, and second, as heterogeneous firms are notoriously hard to capture in a theoretical model. We therefore resort to an experiment.

In a number of treatments we implement different industry configurations that are subject to yardstick competition. We allow experimental subjects to set cost levels in a number of periods. Experimental markets differ in the number of firms (2 or 3) and in the size distribution of firm. In markets with 2 firms, firms either have equal or different sizes; in markets with 3 firms, we look at a case with 3 equally sized firms, a case with one large firms and two smaller firms, and a case where all firms have different sizes. The regulated price is determined by a weighted uniform yardstick (where the price of all firms is determined by the average costs of all firms, weighted by their size), an unweighted uniform yardstick (where the price of all firms is determined by the unweighted average cost of all firms), a discriminatory yardstick (where the price of each firm is determined by the average cost of all *other* firms) and a best-practice yardstick (where the price of each firm is determined by the most efficient firm in the industry). Importantly, in each period we allow market participants to communicate – which should facilitate collusion.

In each treatment, we study to what extent experimental subjects are successful in establishing collusion. That is, we study to what extent they set the cost level that maximizes their joint utility in the one-shot game, rather than the cost level that is the Nash equilibrium of the one-shot game. We look at three measures of collusion: the incidence of full collusion, a collusion index that is 0 in the case of competition and 1 in the case of full collusion, and the resulting market price. By comparing these measures over different treatments, we can establish the extent to which collusion is affected by industry structure and yardstick design.

We find that when market shares are heterogeneous, collusion is least frequent and prices are lowest. The number of players on a market also influences prices, but to a lesser extent. Comparing across yardsticks, the discriminatory yardstick yields the lowest prices, while a best-practice yardstick yields the highest prices.

The remainder of this paper is organized as follows. In the next section we give more background on regulation, yardstick competition, and Dutch practice. Sections 3 and 4 describe the theoretical model. Section 5 presents the setup of our experiment. Section 6 describes our results. Finally, Section 7 concludes.

2 Background

2.1 Yardstick Competition

In the last decades, several network industries which used to be legal monopolies have been liberalized. Some parts of these industries are characterized by subadditivity of costs (Kip Viscusi et al., 2005). Examples include the local loops in telecommunications (Cave and Hatta, 2009) and the distribution grids in the electricity and gas industry. A consequence of the subadditivity of costs is that duplicating these networks is not efficient, which gives their operators a natural monopoly. To enable potential users of these monopolistic networks to obtain access at efficient prices, many countries introduced regulation of these sectors. Besides pursuing allocative efficiency, the purpose of regulation is to enhance productive efficiency in the operation of the networks.

The key measure to realize the objectives of allocative and productive efficiency is the regulation of tariffs. As there is a trade-off between allocative and productive efficiency, the optimal design of the tariff regulation depends on the (social) preferences regarding these two objectives. Price-cap regulation focuses on productive efficiency. Under such regulation, firms receive a fixed tariff for allowing access to their networks. Therefore, the regulated firms face high-powered incentives to reduce costs; any reduction in costs does not affect the tariffs and hence is fully reflected in a firm's profits (Weyman-Jones, 2009). On the other hand, cost-plus regulation focuses on allocative efficiency. Under such regulation, the allowed revenues are equal to the actual costs, including a compensation for the opportunity costs of capital. This, of course, reduces the incentives to operate as efficiently as possible. Every decrease in costs leads to an equal decrease in tariffs and hence does not affect profits. An intermediate method is yardstick competition. Here, regulated firms can charge a maximum tariff that is related to the actual costs of operating the networks, based on information of all firms in the industry. This gives incentives to the regulated firms to operate more efficiently while the tariffs remain related to actual costs.

There are different types of yardstick competition. With a uniform yardstick every firm faces the same tariff, that depends on the (weighted) costs of all firms. With a discriminatory yardstick every firm faces a different tariff: for each firm, the tariff depends on the (weighted) costs of all other firms. Yardstick competition implies that firms do have incentives for productive efficiency, as tariffs largely depend on factors that are exogenous to the regulated firm. In particular, tariffs are partly or fully based on the costs of other firms that are comparable to the regulated firm. If tariffs are fully based on own costs of the regulated firm (as is the case with cost-plus regulation), the incentive power is 0: every decrease in costs leads to an equal decrease in tariffs and hence does not affect profits. On the other hand, if the tariffs are fully based on costs of other firms, the incentive power is 1: in those cases every decrease in costs does not affect the regulated tariffs and hence is fully reflected in the firm's profits. The latter is the case with a discriminatory yardstick. With a uniform yardstick the incentive power is strictly between 0 and 1: in that case, every decrease in costs leads to a less that proportional decrease in the regulated tariff. Hence profits change by less than the total change in costs (see Shleifer, 1985).

2.2 Dutch Practice

In the Dutch energy distribution industry, for both electricity and gas, a form of uniform-yardstick competition has been in place for about a decade. These industries consist of a number of regional monopolies. When yardstick competition was introduced, the number of regulated networks was about 15, while the differences in size were relatively modest. Since then, the number of firms has decreased strongly as a result of mergers and acquisitions. Currently, both the electricity and the gas distribution industry consist of about 7 regulated firms, with a few players having a market share of about 30%, while the others are significantly smaller (NMa, 2010).

Generally, the length of the regulatory periods is 3 to 5 years. For the energy-distribution grids, the yardstick is defined as the average costs per unit of output in the industry. These average costs are calculated on the basis of the realized costs in the last year before the new regulatory period starts. To take account of general changes in productivity (the *frontier shift*), these past average costs are corrected for the expected change in productivity to obtain the level of the yardstick. As the yardstick is expressed per unit of output, the regulator also needs to make an assumption on the total volume of output in order to determine the level of efficient costs (EC) at the end of the new regulatory period. The network operator therefore faces a volume risk which is reflected in the costs of capital. The maximum revenues that a firm is allowed to receive during each year of this period follow from the X-factor: this is the average annual percentage change needed to take the actual revenues (R) of each firm in the last year before the new regulatory period, to the level of maximum revenues allowed at the end of that period:

$$X = 1 - \frac{EC_{t=ln}^{1/N}}{R_{t=lp}} \tag{1}$$

with N the length of the regulatory period in years (t), ln the last year of new regulatory period and lp the last year of previous regulatory period. Note that this regulatory regime determines a cap on the annual revenues, not on actual tariffs: in principle, the firms are free to choose the tariffs for different type of products and different types of customer groups, as long as the aggregate value of tariffs multiplied by volumes does not exceed the cap on revenues.

We expect that yardstick competition has become less effective in the Netherlands due to recent changes in the industry structure. With fewer firms, the incentive power for each individual firm has decreased, as it has a stronger influence on the regulated tariff. Moreover, these changes may affect not only the incentive power in a competitive setting, but also the ability of firms to coordinate on both the level and the timing of costs. We now turn to that issue.

2.3 Incentive to Collude

The discussion on incentive power in section 2.1 implicitly assumes that firms behave unilaterally and independently from each other. But now suppose they act as a cartel, maximizing joint profits. From the point of view of the full cartel, the incentive power of regulation will be different from that of an individual firm. In fact, both with a uniform as well as with a discriminatory yardstick, the incentive power for the full cartel is now 0: if the entire industry manages to lower its cost, then that cost decrease will be fully reflected in the regulated tariff, hence profits of the cartel will not be affected. Collusion thus leads to a lower incentive power. Hence, costs are likely to be higher as a result.

To test the sensitivity of yardstick competition to collusion, Potters et al. (2004), do an experiment in which they compare a discriminatory yardstick with a uniform yardstick, in a market with two local monopolists. The competitive outcome is lower with a discriminatory than with a uniform yardstick. As full collusion yields the same outcome with both yardsticks, establishing a cartel yields a stronger increase in profits with a discriminatory rather than with a uniform yardstick. Potters et al. (2004) do indeed observe more collusion with a discriminatory yardstick.

In regular markets (i.e. where firms set prices or quantities in a competitive environment, rather than cost levels on a regulated market) it is well known that the incentive to collude also depend on the number of firms. When more firms are active it is more difficult to establish a cartel (see, e.g., Huck et al., 2004). The same may be true in regulated markets, although so far there has been no experimental or empirical evidence for that. On the basis of a theoretical model, however, Tangerås (2002) concludes that regulators need to be careful in assessing mergers of regulated firms. Moreover, Haffner et al. (2006) conclude that there need to be at least 5 firms in a market if yardstick competition is applied.

In regular markets, the possibilities of behaving strategically also depends on the heterogeneity of firms. The larger the differences between firms, the more difficult it is to reach an (implicit) agreement (see, a.o., Motta, 2004). For the same reason, we also expect that a regulated market with more firm heterogeneity would make yardstick competition more effective in that firms are less likely to collude.

2.4 Conclusion

Above, we noted that regulation of electricity and gas networks in the Netherlands can essentially be characterized as one with a weighted uniform yardstick. Also, we observed a trend towards mergers and consolidation in these industries, leading to fewer firms determining the yardstick. Moreover, we observed that the consensus in the academic literature seems to be that collusion is facilitated by market structures with fewer and more homogeneous firms. At the same time, we noted that the design of yardstick may influence the extent to which an industry is prone to collusion.

These observations give rise to a number of important questions. If there would be more mergers or acquisitions among Dutch energy distribution networks, would that make it more likely that firms collude in yardstick competition? If so, would consolidation to roughly equally-sized firms make collusion even more likely? And does the design of the yardstick have an effect on the extent of collusion?

In the remainder of this paper, we address these questions using an economic experiment. Such experiments are particularly valuable when empirical data is lacking. With yardstick competition, that is exactly the case. Only realized costs are known, and data for counterfactuals with a different number or size distribution of firms are impossible to obtain. In such circumstances, an experiment is an efficient way to collect data. It allows us to analyze behaviour of economic agents under conditions that are fully controlled. For a meaningful analysis, it is essential that players have a good understanding of the game, that they play anonymously, and that payoffs they obtain are converted in real money using a fixed exchange rate.

In the remainder of this paper, we first present a simple theoretical model that serves as the basis for our experiment. We derive the implications of that model and then discuss how we implement it in a laboratory experiment. Finally, we discuss the results of that experiment.

3 Setup

Our experiment is based on Potters et al. (2004). Subjects play a finitely repeated game consisting of several rounds. Every round is a regulatory period: subjects need to set average costs, and based on these costs the tariff is determined. Furthermore, subjects can have unrestricted communication in every round before deciding what cost level to set. At the end of each round, subjects observe the tariff, which is based on these average cost levels. For simplicity, costs thus have to be set once in every regulatory period, and costs implemented in a round only affect prices and profits in that round. Note from section 2.2 that the timing is somewhat different in reality, but that does not materially affect incentives.

We consider a regulated market, in which n firms are active, $n \in \{2, 3\}$. Each firm has its own submarket. The share of firm i in the total market is denoted $\alpha_i \in [0, 1)$ with $\sum_{i=1}^{n} \alpha_i = 1$. If only 2 firms are active, we have $\alpha_3 = 0$. The total size of the market is denoted D. For experimental simplicity, we assume that market size is fixed and does not depend on prices that are set.

Firms in this market play a repeated game. In every period, the manager of each firm chooses his marginal cost level c for that period. Total utility of a manager in a period equals firm profits plus a managerial benefit $R(c)$ that depends on the choice of marginal costs:

$$u_i = \pi_i(c_i) + R_i(c_i), \tag{2}$$

with π profits and R managerial benefits. We first discuss the latter.

In the literature (see e.g. Shleifer, 1985) it is routinely assumed that to become more efficient (and hence to decrease c), a manager has to exert some costly effort, and the amount of effort required is an increasing and convex function of the desired efficiency gain. This implies that the managerial benefit R is increasing in c, but at a decreasing rate. In our implementation, we assume

$$R(c_i) = \left(-ac_i^2 + bc_i\right) \alpha_i D, \tag{3}$$

where a and b are parameters. We thus assume that managerial benefit is proportional to market share. This is for consistency: if the market is shared among more firms, we do not want total managerial benefit to exogenously increase as a result. Managerial benefit is maximized when setting $c^{m*} = \frac{b}{2a}$.

It is worth noting that the specification we chose for managerial benefit is a concave function, but also has a decreasing part. The main reason for making that choice is that it simplifies the maximization problem of our experimental subjects, as we will see below. Still, we do believe that this particularly shape can also be justified on theoretical grounds. First, in electricity networks for example, very high marginal costs are associated with a network that has been neglected for years and on which the necessary maintenance has not been performed. Such networks, however, are also more prone to outages, compensation claims, and political pressure to improve the network. All these factors ultimately imply lower managerial benefits.

The second reason why we feel it is justified for our managerial benefit to also have a decreasing part is more technical. Note that in our set-up we assume that demand is fixed and does not depend on prices. In the more realistic set-up that demand does depend on prices, total utility as a function of marginal costs can be shown to indeed be strictly decreasing for high enough c.

Profits of firm i are given by

$$\pi_i = (p_i - c_i)\alpha_i D, \tag{4}$$

with p_i the price that firm i can set. This price may be subject to regulation. We consider four yardsticks, and derive the exact expression for the regulated price that those yardsticks imply.

Consider firm 1. With a uniform weighted yardstick, the price it can charge equals the weighted average of all cost levels in the industry:

$$p^{UW}(c_1, c_2, c_3) = \alpha_1 c_1 + \alpha_2 c_2 + \alpha_3 c_3. \tag{5}$$

With a uniform unweighted yardstick, it equals the unweighted average of all cost levels in the industry:

$$p^{UU}(c_1, c_2, c_3) = \frac{c_1 + c_2 + c_3}{n}. \tag{6}$$

With a discriminatory yardstick, the price firm 1 can charge equals the weighted average of the cost levels of all *other* firms in the industry:

$$p_1^D(c_1, c_2, c_3) = \frac{\alpha_2 c_2 + \alpha_3 c_3}{\alpha_2 + \alpha_3}. \tag{7}$$

With the most-efficient or best-practice yardstick, it equals the lowest cost level of all firms in the industry:

$$p^{BP}(c_1, c_2, c_3) = \min\{c_1, c_2, c_3\}. \tag{8}$$

Note that our notation reflects that the price is firm-specific under a discriminatory yardstick, but that all firms charge the same price under the other yardstick designs.

4 Equilibrium

4.1 Introduction

In this section, we analyze the model we set up in the previous section. For each yardstick design, we derive the Nash equilibrium of the stage game. We also derive the cost levels for the case in which managers collude to maximize their joint utility in each period. We then compare all yardsticks on these two dimensions. Throughout this section, we assume that the parameters a and b are such that all expressions we obtain are well-defined.

First, it is instructive to show what a social planner would do. Suppose consumers value one unit of the product at v. Total welfare then equals

$$W = (v - p)\, D + (p - c)\, D + \left(-ac^2 + bc\right) D, \tag{9}$$

where the first term reflects consumer surplus, whereas the last two terms is the total payoff to firms. As we assume that demand is completely inelastic, prices are only a transfer between consumers and firms, and drop out of the welfare equation.

Maximizing welfare with respect to c yields

$$c^W = \frac{b-1}{2a}. \tag{10}$$

4.2 Uniform Weighted Yardstick

Consider the manager of firm 1. With a uniform weighted yardstick, his utility is

$$u_1\left(c_1, c_2, c_3\right) = \left(\alpha_1 c_1 + \alpha_2 c_2 + \alpha_3 c_3 - c_1\right) \alpha_1 D + \left(-ac_1^2 + bc_1\right) \alpha_1 D. \tag{11}$$

Maximizing with respect to c_1 yields

$$\frac{\partial u_1}{\partial c_1} = \alpha_1 - 1 - 2ac_1 + b = 0 \tag{12}$$

which yields the equilibrium, or competitive, cost level

$$c_1^{UW*} = \frac{b - 1 + \alpha_1}{2a}. \tag{13}$$

First note that this is a dominant strategy, as it does not depend on the cost choices of the other firms. The second thing worth noting is that a firm with a higher market share α_1 has a stronger influence on the regulated price, which also implies that it will choose a higher cost level. Third, as long as $\alpha_1 < 1$, the equilibrium cost level is strictly lower than the cost level that maximizes managerial benefits (which was given by $c^{m*} = b/2a$). In this set-up, higher costs adversely affect profits, giving managers an additional incentive to choose lower costs.

Now suppose that firms collude and choose a common cost level c_k. In that case, the regulated price simply equals $p^{UW} = c_k$, and the price-cost margin for all firms equals $p^{UW} - c_k = 0$. Total utility for all managers thus equals

$$U = \left(p^{UW} - c_k\right) D + \left(-ac_k^2 + bc_k\right) D = \left(-ac_k^2 + bc_k\right) D, \tag{14}$$

which is maximized by setting

$$c_k^* = c^{m*} = b/2a. \tag{15}$$

As a joint cost level does not affect the price-cost margin, the cartel simply chooses to maximize its managerial benefit. Note that we also obtain this solution by setting $\alpha_1 = 1$ in (13).

4.3 Uniform Unweighted Yardstick

With a uniform unweighted yardstick, the total pay-off for firm 1 is given by

$$u_1\left(c_1, c_2, c_3\right) = \left(\frac{c_1 + c_2 + c_3}{n} - c_1\right) \alpha_1 D + \left(-ac_1^2 + bc_1\right) \alpha_1 D. \tag{16}$$

Maximizing with respect to c_1 yields

$$\frac{\partial u_1}{\partial c_1} = \frac{1}{n} - 1 - 2ac_1 + b = 0 \tag{17}$$

which yields the optimal cost level c_1^{UU*} of

$$c_1^{UU*} = \frac{b - 1 + \frac{1}{n}}{2a} \tag{18}$$

If all firms set the same c, it is easy to see that $p^{UU} = c_k^*$. Hence, the cartel outcome is the same as that in (15).

4.4 Discriminatory Yardstick

With a discriminatory yardstick, the total pay-off for firm 1 is given by

$$u_1\left(c_1, c_2, c_3\right) = \left(\frac{\alpha_2 c_2 + \alpha_3 c_3}{\alpha_2 + \alpha_3} - c_1\right) \alpha_1 D + \left(-ac_1^2 + bc_1\right) \alpha_1 D. \tag{19}$$

Maximizing with respect to c_1 yields

$$\frac{\partial u_1}{\partial c_1} = -1 - 2ac_1 + b = 0 \tag{20}$$

which yields the optimal cost level c_1^{D*} of

$$c_1^{D*} = \frac{b-1}{2a}. \tag{21}$$

Note therefore that this yardstick yields the social welfare optimum derived in (10).

If all firms set the same c, it is easy to see that $p_i^D = c_k^* \ \forall i$. Hence, the cartel outcome is the same as that in (15).

4.5 Most-efficient Yardstick

Finding the Nash equilibrium of the stage game when the most-efficient yardstick is used, is somewhat more involved. Suppose all other firms set c^*. By setting some $c < c^*$, this firm earns

$$u_1(c_1, c_2, c_3) = (c - c)\,\alpha_1 D + \left(-ac^2 + bc\right)\alpha_1 D, \tag{22}$$

which is maximized by setting

$$c = \frac{b}{2a}. \tag{23}$$

This implies that if the other firms set some $c^* \leq b/2a$, this firm has no incentive to defect to a lower cost level: its maximization problem under the constraint that $c \leq c^*$ is solved by $c = c^*$.

By setting some $c > c^*$, this firm earns

$$u_1(c_1, c_2, c_3) = (c^* - c)\,\alpha_1 D + \left(-ac^2 + bc\right)\alpha_1 D, \tag{24}$$

which is maximized by setting

$$c = \frac{b-1}{2a}. \tag{25}$$

This implies that if the other firms set some $c^* \geq (b-1)/2a$, this firm has no incentive to defect to a higher cost level: its maximization problem under the constraint that $c \geq c^*$ is solved by $c = c^*$).

This implies that we have a continuum of equilibria: any $c^{BP*} \in [(b-1)/2a, b/2a]$ is a Nash equilibrium. Thus, with a most-efficient yardstick, even the cartel outcome could be a Nash equilibrium of the stage game.

4.6 Comparison of Yardsticks

4.6.1 Competition

Next, we compare the competitive cost levels of all different yardsticks, by calculating the prices that result. With a uniform weighted yardstick the regulated price becomes

$$p^{UW*} = \sum_{i=1}^{n} \alpha_i c_i^{UW*} = \sum_{i=1}^{n} \alpha_i \frac{b-1+\alpha_i}{2a} = \frac{b-1}{2a} + \frac{\sum_{i=1}^{n} \alpha_i^2}{2a}. \quad (26)$$

The price with a uniform unweighted yardstick is

$$p^{UU*} = \frac{1}{n} \sum_{i=1}^{n} c_i^{UU*} = \frac{1}{n} \sum_{i=1}^{n} \frac{b-1+\frac{1}{n}}{2a} = \frac{b-1}{2a} + \frac{\frac{1}{n}}{2a}. \quad (27)$$

With a discriminatory yardstick, the regulated price differs per firm. Note however that the regulated price p_i^{D*} that firm i can charge does not depend on the market share of this firm. Since a share of α_i of total demand is supplied by firm i, the average regulated price is

$$p^{D*} = \sum_{i=1}^{n} \alpha_i p_i^{D*} = \sum_{i=1}^{n} \alpha_i \frac{b-1}{2a} = \frac{b-1}{2a}. \quad (28)$$

Finally, with a most-efficient yardstick there is a continuum of equilibria. The equilibrium with the lowest cost level results in a regulated price of

$$p^{BP*} = \frac{b-1}{2a}. \quad (29)$$

In the remainder of this paper, for ease of discussion, we will refer to the price levels that result if all firms play the Nash equilibrium of the stage game, as the "competitive price level". Note that this is something of a misnomer, as we still look at regulated prices. Hence, "competitive" refers to the fact that firms do not collude, rather than that they truly compete in prices.

Obviously, the discriminatory and best practice yardsticks result in the lowest competitive price levels. The highest prices can be charged with the uniform yardsticks. Only when the market is completely homogeneous in terms of firm size, i.e. when $\alpha_i = \frac{1}{n}\ \forall i$, the competitive-level prices in (26) and (27) are equal. Otherwise, a uniform weighted yardstick results in a higher competitive price level than a uniform unweighted yardstick.

Theoretical Result 1. *The competitive prices are ranked*

$$\textit{Discriminatory} = \textit{Best Practice} < \textit{Uniform Unweighted} \leq \textit{Uniform Weighted}.$$

Only with symmetric market shares, Uniform Unweighted = Uniform Weighted.

4.6.2 Collusion

We now turn our attention to the (infinitely) repeated game. We assume that firms use standard grim trigger strategies (Friedman, 1971). Then, each firm will set the collusive cost level c_k^* in every round as long as no firm has deviated from this cost level. After a deviation, firms revert to the Nash equilibrium forever, i.e. the competitive cost level. Furthermore, we assume that firms discount future profits by a common discount factor $\delta \in (0,1)$.

More formally, we define u_i^K as the utility of the manager of firm i in a round where all firms set the collusive cost level, i.e.

$$u_i^K = \left(-a\left(c_k^*\right)^2 + bc_k^*\right)\alpha_i D = \frac{\alpha_i D}{4a} b^2. \tag{30}$$

Furthermore, we define u_i^N as this manager's utility in a round where all firms set the competitive cost level, i.e.

$$u_i^N = \left(p^{y*} - c_i^{y*}\right)\alpha_i D + \left(-a\left(c_i^{y*}\right)^2 + bc_i^{y*}\right)\alpha_i D, \tag{31}$$

where $y \in \{\text{UW, UU, D, BP}\}$. These values equal

$$\text{UW:} \quad u_i^N = \frac{\alpha_i D}{4a}\left(b^2 - 1 + 2\sum_{j=1}^{n}\alpha_j^2 - \alpha_i^2\right) \tag{32}$$

$$\text{UU:} \quad u_i^N = \frac{\alpha_i D}{4a}\left(b^2 - \left(\frac{n-1}{n}\right)^2\right) \tag{33}$$

$$\text{D:} \quad u_i^N = \frac{\alpha_i D}{4a}\left(b^2 - 1\right) \tag{34}$$

$$\text{BP:} \quad u_i^N = \frac{\alpha_i D}{4a}\left(b^2 - 1\right). \tag{35}$$

Finally, we define u_i^D as the utility of the manager of firm i in a round where he deviates from the collusive cost level, i.e.

$$u_i^D = \left(p^y\left(c_i^{y*}, c_k^*, c_k^*\right) - c_i^{y*}\right)\alpha_i D + \left(-a\left(c_i^{y*}\right)^2 + bc_i^{y*}\right)\alpha_i D. \tag{36}$$

Remember that we already showed that the one-shot optimal cost level for firm i is independent of the cost levels of the other firms. Therefore, the optimal deviation cost level is equal to the competitive cost level. This results in the following deviation utilities:

$$\text{UW:} \quad u_i^D = \frac{\alpha_i D}{4a}\left(b^2 + 1 + \alpha_i^2 - 2\alpha_i\right) \tag{37}$$

$$\text{UU:} \quad u_i^D = \frac{\alpha_i D}{4a}\left(b^2 + \left(\frac{n-1}{n}\right)^2\right) \tag{38}$$

$$\text{D:} \quad u_i^D = \frac{\alpha_i D}{4a}\left(b^2 + 1\right) \tag{39}$$

$$\text{BP:} \quad u_i^D = \frac{\alpha_i D}{4a}\left(b^2 - 1\right). \tag{40}$$

We see that one-shot deviation profits decrease with market share under Uniform Weighted. Thus, smaller players have higher incentives to lower their cost level than larger players.

Firm i will not deviate if and only if

$$\frac{1}{1-\delta}u_i^K \geq u_i^D + \frac{\delta}{1-\delta}u_i^N, \tag{41}$$

which results in the critical discount factor

$$\delta \geq \delta_i^K \equiv \frac{u_i^D - u_i^K}{u_i^D - u_i^N}. \tag{42}$$

An equilibrium that sustains collusion exists if and only if all firms are willing to collude, i.e. if and only if $\delta \geq \delta^K \equiv \max\{\delta_1^K, \delta_2^K, \delta_3^K\}$. For every type of yardstick the critical discount factors are equal to:

$$\text{UW:} \quad \delta_i^K = \frac{1}{2}\frac{(1-\alpha_i)^2}{1-\alpha_i - \sum_{j=1}^n \alpha_j^2 + \alpha_i^2} \tag{43}$$

$$\text{UU:} \quad \delta^K = \frac{1}{2} \tag{44}$$

$$\text{D:} \quad \delta^K = \frac{1}{2} \tag{45}$$

$$\text{BP:} \quad \delta^K = 0. \tag{46}$$

Note that the critical discount factor under Uniform Unweighted, Discriminatory and Best Practice, are the same for each firm, irrespective of firm size. Furthermore, under Best Practice collusion is always sustainable, since deviation profits are equal to competitive profits.

The incentive power for each player to lower its cost level depends on the type of yardstick design. The incentive power also depends on market share under Uniform Weighted, or on the number of firms with Uniform Unweighted. With Discriminatory the incentive power is always 1, while in Best Practice the incentive power is 0 if the firm is already the most efficient or 1 otherwise.

We present the following result.

Theoretical Result 2. *The highest critical discount factors (i.e. the probabilities of collusion) are ranked*

$$\textit{Best Practice} < \textit{Uniform Unweighted} = \textit{Discriminatory} \leq \textit{Uniform Weighted}.$$

Only with symmetric market shares, Discriminatory = Uniform Weighted.

5 Experimental Design

In our experiment, subjects play the game for at least 20 rounds. We use fixed matching: every subject plays with the same group members in all rounds. After 20 rounds, there is a fixed probability of 20% in each round that the experiment ends. It is well known that in a finitely repeated game, the unique equilibrium is for subjects to play the Nash equilibrium of the stage game in each single round. By incorporating a termination probability, there is no fixed and commonly known end date, so we avoid this problem.

Every round consists of three steps. In the first step, subjects can communicate using a chat screen. This is rather unusual in this type of experiments. We implement communication possibilities to get circumstances as close as possible to those in the real world, and in order to increase chances of obtaining collusion. It is well known from cartel experiments that, without communication, it is hard to sustain collusion if there are more than two players. As a second step, subjects choose average cost levels.

Third, price is determined by the regulator (using either a discriminatory, a uniform, or a most-efficient benchmark), and profits and managerial benefits are realized.

Experimental subjects receive a fixed amount for participation and, based on their decisions, may gain an additional amount of money. Hence, the higher their pay-off in the game, the higher the amount that they take home. This implies that incentives of our subjects are in line with those in the theoretical model. The fixed amount can be regarded as a financial buffer which firms created over time. This buffer ensures that firms will not go bankrupt if they make a loss during a round. That possibility would boil down to firms having limited liability, which may strongly influence their behavior.

We run 5 treatments with a uniform weighted yardstick. These treatments are presented in Table 1. The table also shows for each treatment the competitive cost level of each firm, yardstick that results, and the symmetric cost level that maximizes joint profits. Throughout, we set $D = 12$, $a = 1/24$, and $b = 1$. These choices make sure that the competitive and collusive cost levels derived above, are integers.

Treatment	Market Share				Competitive Cost Level				Collusive Cost Level
	α_1	α_2	α_3	HHI	c_1^*	c_2^*	c_3^*	yardstick	
Trio444	33.33%	33.33%	33.33%	3333	4	4	4	4.00	12
Trio633	50.00%	25.00%	25.00%	3750	6	3	3	4.50	12
Trio642	50.00%	33.33%	16.67%	3889	6	4	2	4.67	12
Duo66	50.00%	50.00%		5000	6	6		6.00	12
Duo84	66.67%	33.33%		5556	8	4		6.67	12

Table 1: Setup of the treatments with a uniform weighted yardstick.

Note from Table 1 that competitive cost levels differ with the number of firms and also with the composition of market shares. It is higher with 2 firms rather than 3 firms. A decrease in the number of firms thus increases competitive cost levels. This follows directly from (13).

Theoretical Result 3. *A decrease in the number of firms increases competitive cost levels with a uniform weighted yardstick.*

Another conclusion from Table 1 is that as market shares become more heterogeneous, competitive cost levels increase. Hence, from a productive efficiency point of view, a more homogeneous market is preferable. However, we also saw that a more homogeneous market makes it easier to sustain collusion. Which of these two effects dominates remains to be seen in our experiment.

Theoretical Result 4. *Given the number of firms, the competitive levels with a uniform weighted yardstick decrease when market shares become more homogeneous.*

The treatments above are chosen to facilitate the object of our study: to evaluate the effect of a change in the number of firms, and a change in the heterogeneity of firms, on market performance in terms of cost levels. We compare the treatments in a pairwise fashion:

- Trio444-Trio633 and Trio444-Trio642: Effect of heterogeneity with 3 firms;
- Trio633-Trio642: Effect of different heterogeneity with 3 firms;
- Trio444-Duo66: Effect of number of firms;
- Trio633-Duo66 and Trio642-Duo66: Effect of number of firms and heterogeneity;
- Trio444-Duo84: Effect of number of firms and heterogeneity;
- Duo66-Duo84: Effect of heterogeneity with 2 firms.

We are also interested in the extent to which firms are able to collude. Table 2 gives the critical discount factors to sustain collusion in each treatment.

Treatment	Firm 1	Firm 2	Firm 3	Maximum
Trio444	50%	50%	50%	50%
Trio633	33%	64%	64%	64%
Trio642	33%	57%	71%	71%
Duo66	50%	50%		50%
Duo84	25%	100%		100%

Table 2: Overview of critical discount factors for treatments with a uniform weighted yardstick.

Based on the last column of Table 2 we do not expect differences in the level of collusion between all treatments with three players and Duo66. However, following Bigoni et al.

(2012) we will examine the tightness of the incentive compatibility constraint (41) of all treatments. An incentive compatibility constraint is tighter if the difference between the values of colluding and deviating is smaller. If these constraints are tighter, we argue that it is more difficult to sustain collusion. A tighter incentive compatibility constraint (41) results in a higher critical discount factor in (42). Thus, we expect most collusion to occur in the treatments with the lowest critical discount factors. Therefore, we expect most collusion in Trio444 and Duo66, followed in order of decreasing magnitude by Trio633, Trio642, and Duo84. Finally, we expect more collusion in Duo66 than in Trio444, because there are less firms in the former than in the latter treatment.

In summary, we present the following hypothesis about collusion for treatments with a uniform yardstick.

Hypothesis 1. *There will be most collusion in Duo66, followed in order of decreasing magnitude by Trio444, Trio633, Trio642, and Duo84.*

Furthermore, we will run treatment Duo84 with different yardsticks. These treatments are presented in Table 3, where Weighted is the same as Duo84. As already shown in

Treatment	Competitive Cost Level			Collusive Cost Level
	c_1^*	c_2^*	yardstick	
Weighted	8	4	6.67	12
Unweighted	6	6	6.00	12
Discriminatory	1	1	1.00	12
Best Practice	1	1	1.00	12

Table 3: Setup of the treatments with different yardsticks. All treatments: α_1 =66.67%, α_2 =33.33% and HHI=5556.

section 4.6, the most competitive yardsticks from a theoretical perspective are Discriminatory and Best Practice. The current type of yardstick competition, Weighted, results theoretically in the highest competitive yardstick.

Table 4 gives the critical discount factors to sustain collusion in each treatment. This yields the following hypothesis[1]

[1]Note that there is a small difference between Theoretical Result 2 and Hypothesis 2. Since our experiment requires subjects to choose from a discrete set with only positive cost levels, the critical discount factor for Discriminatory is slightly higher.

Treatment	Firm 1	Firm 2	Maximum
Weighted	25%	100%	100%
Unweighted	50%	50%	50%
Discriminatory	54%	54%	54%
Best Practice	0%	0%	0%

Table 4: Overview of critical discount factors for treatments with different yardsticks.

Hypothesis 2. *Most collusion will be found in Best Practice, followed in order of decreasing magnitude by Uniform Unweighted, Discriminatory, and Uniform Weighted.*

6 Results

The experiment was conducted in February and March 2013 at the Groningen Experimental Economics Laboratory (GrEELab) at the Faculty of Economics and Business of the University of Groningen. A total of 314 subjects participated which were all students from the University of Groningen (81.2%) or the Hanze University of Applied Sciences (18.8%). Most students were doing an economics major (62.7%). Every session consisted of one treatment and lasted between 80 and 115 minutes. Subjects were randomly assigned to treatments.

Every treatment with 2 players was run twice whereas every treatment with 3 players was run three times. Between 14 and 18 subjects participated in a session, resulting in 15 to 18 groups per treatment. This number of groups is similar to other experiments, see e.g. Bigoni et al. (2012), Dijkstra et al. (2011) and Hinloopen and Soetevent (2008).

The experiment was programmed in z-Tree (Fischbacher, 2007). Printed instructions were provided and read aloud.[2] On their computer, subjects first had to answer a number of questions correctly to ensure understanding of the experiment. Participants were paid their cumulative earnings in euros. Since firm size differed between treatments, exchange rates were varied such that participants would receive identical amounts if they fully colluded. Furthermore, they received an initial endowment of €4. Average earnings were €16.80 and ranged from €6.60 to €24.00.

[2] Instructions for Trio633 are reproduced in Appendix B. Instructions for other treatments are similar and available upon request.

Below, we compare the treatments in a pairwise fashion. We only analyze the first 20 rounds of each group. We use the non-parametric Mann-Whitney U Test (MWU) throughout this section to test for equality of two populations. All significance levels reported are for the no-treatment effect versus the one-sided alternative.

We first look at the effect of market structure, under a uniform weighted yardstick. We first study which treatment is most prone to full collusion, i.e. firms choosing a cost level of 12. As an alternative measure for collusion we look at a collusion index, that takes the value 0 if firms set the fully competitive cost level, and the value 1 if they set the fully collusive level. Finally, we look at the effect of prices. This is the total of two separate effects. First, market structure will affect the competitive level of costs, as we saw in section 4. Second, market structure may also affect the extent to which firms are able to form a cartel.

6.1 Results Market Structure

6.1.1 Collusion

We first look at the extent to which firms are able to form a cartel, i.e. to set cost levels that are equal the fully collusive level of 12. For each treatment, the fraction of markets that are fully collusive is depicted in Figure 1. We see that the number of markets where a cartel is established is substantial. There are no clear time trends. From the figure, Trio444 seems the most collusive, while the least collusion is found in Trio642. This suggests that more heterogeneity makes it more difficult to collude.

Table 5 gives summary statistics. The right-hand panel indicates whether the row treatment yields a rate of collusion that is significantly lower ($<$), significantly higher ($>$) or that does not differ significantly ($\approx$) from the rate in the column treatment. We thus see that Trio444 leads to significantly more collusion than Trio642, Duo66, and Duo84. The difference with Trio633 is not significant. Overall, the table suggests that more collusion occurs if the market structure is more homogeneous – at least in treatments with 3 firms. For the 2-firm treatments, we do not find a significant effect of heterogeneity. The table also suggests that a merger from a homogeneous to a more

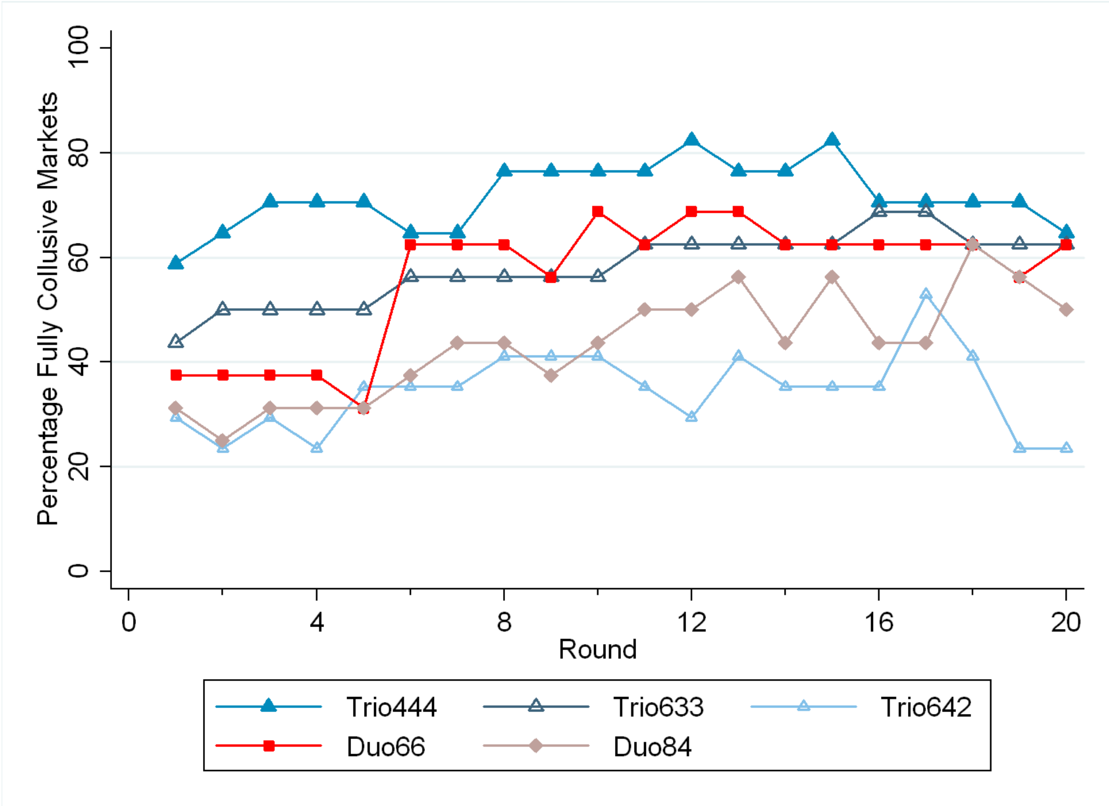


Figure 1: Average percentage of markets per round where every firm set the collusive cost level of 12 (across all groups).

heterogeneous market structure with less firms (Trio444 to Duo84) yields significantly less collusion, whereas a merger from a heterogeneous to a more homogeneous market structure (Trio642 to Duo66) significantly increases the amount of collusion. In that sense, the extent of heterogeneity is more important for collusion than the number of firms.

Table 6 reports on four logit estimates where we look at the effect of heterogeneity while keeping the number of firms constant, and vice-versa. From column (2), we see that in markets with 3 firms, there is significantly less collusion if firms are heterogeneous rather than homogeneous. From column (1), this is also the case in markets with 2 firms, but in that case the difference is not significant. Surprisingly, with 3 firms we find more collusion than with 2 firms (columns (3) and (4)), but this effect is not significant.

Treatment	Average	Median	Trio633	Trio642	Duo66	Duo84
Trio444	71.8%	95.0%	$\approx$	$>^{**}$	$>^{+}$	$>^{*}$
Trio633	58.1%	77.5%		$>^{+}$	$\approx$	$\approx$
Trio642	34.4%	15.0%			$<^{*}$	$\approx$
Duo66	56.3%	52.5%				$\approx$
Duo84	43.4%	32.5%				

Entries in the right-hand panel indicate whether the row treatment yields rates of full collusion that are significantly lower (<), significantly higher (>) or that do not differ significantly ($\approx$) from the rates in the column treatment. $^{+}$ significantly different at 10%; * at 5%; ** at 1% (MWU test for equality).

Table 5: Incidence of full collusion per treatment (across all rounds and groups).

	(1) 2 firms	(2) 3 firms	(3) Homogeneous	(4) Heterogeneous
heterogeneous	-1.293	-3.948*		
	(1.212)	(1.639)		
three firms			2.183	0.753
			(1.354)	(1.511)
constant	0.541	3.658**	0.591	-1.034
	(0.855)	(1.205)	(0.988)	(1.220)
lnsig2u				
constant	2.444***	3.458***	2.761***	3.185***
	(0.378)	(0.368)	(0.406)	(0.348)
Observations	640	1000	660	980

Random-effects binomial logit models for fully collusive markets. Standard errors in parentheses. $^{+}$significant at 10%; *at 5%; **at 1%; ***at 0.1%. The regression in Column (1) includes data from treatments Duo66 and Duo84, that in Column (2) from Trio444, Trio633 and Trio642, that in column (3) from Duo66 and Trio444, and that in column (4) from Duo84, Trio633 and Trio642.

Table 6: Regression results for incidence of full collusion.

Summarizing, we find:

Result 1. *With a uniform weighted yardstick,*

(a) collusion decreases if market shares become more heterogeneous;

(b) the heterogeneity of market shares is more important than the number of firms.

We showed in our theoretical analysis that smaller firms have a higher incentive to deviate from a collusive agreement. Table 7 looks at rounds in which full collusion is not successful, in the sense that at least one firm does not set the fully collusive cost level of 12. For those rounds, the Table gives summary statistics on the percentage of players that do set the fully collusive cost level of 12.

Treatment	Firm Size of Player		
	Small	Intermediate	Large
Trio633	15.1%		26.6%
Trio642	17.5%	18.9%	19.9%
Duo84	27.3%		16.2%

Table 7: Average percentage of players setting the fully collusive cost level of 12 (only rounds are included in which not all firms in a group set the fully collusive cost level of 12)

It seems that smaller firms are somewhat less inclined to collude than larger firms. To investigate whether the differences are significant, we estimate logit models where we look at the effect of firm size on the probability of setting the fully collusive cost level of 12. Results are provided in Table 8. Although smaller firms are less collusive in general, the differences are not significant. Also in Trio642, the only treatment where each player

	Trio633	Trio642	Duo84
large	0.709	0.107	-0.0164
	(0.547)	(0.469)	(0.689)
intermediate		-0.00531	
		(0.473)	
constant	-2.475***	-1.774***	-2.093***
	(0.346)	(0.339)	(0.483)
lnsig2u			
constant	-0.0805	-0.0383	0.651
	(0.618)	(0.416)	(0.569)
Observations	402	669	362

Random-effects binomial logit models for fully collusive markets. Standard errors in parentheses. Only rounds are included in which not all firms in a group set the fully collusive cost level of 12. $^{+}$ significant at 10%; * at 5%; ** at 1%; *** at 0.1%.

Table 8: Regression results for incidence of full collusion at the individual level.

has a different size, there is no significant effect of firm size.[3]

[3] A t-test indicates that the difference in coefficients between large and intermediate is not statistically significant (p-value of .8118).

6.1.2 Collusion Index

Arguably, it is not only important how often firms are able to achieve the perfectly collusive outcome, but also more generally to what extent they are able to achieve a price level that is higher than the competitive outcome. As the competitive outcome differs across market structures, however, we look at the collusion index, that measures the relative premium that firms are able to achieve over and above the competitive outcome:

$$\text{collusion index} \equiv \frac{\text{price} - p^{UW*}}{12 - p^{UW*}}. \tag{47}$$

Thus, if the competitive outcome is achieved, the collusion index equals 0, and if the collusive outcome of 12 is achieved it equals 1. The higher the value of the index, the more successful firms are in colluding.

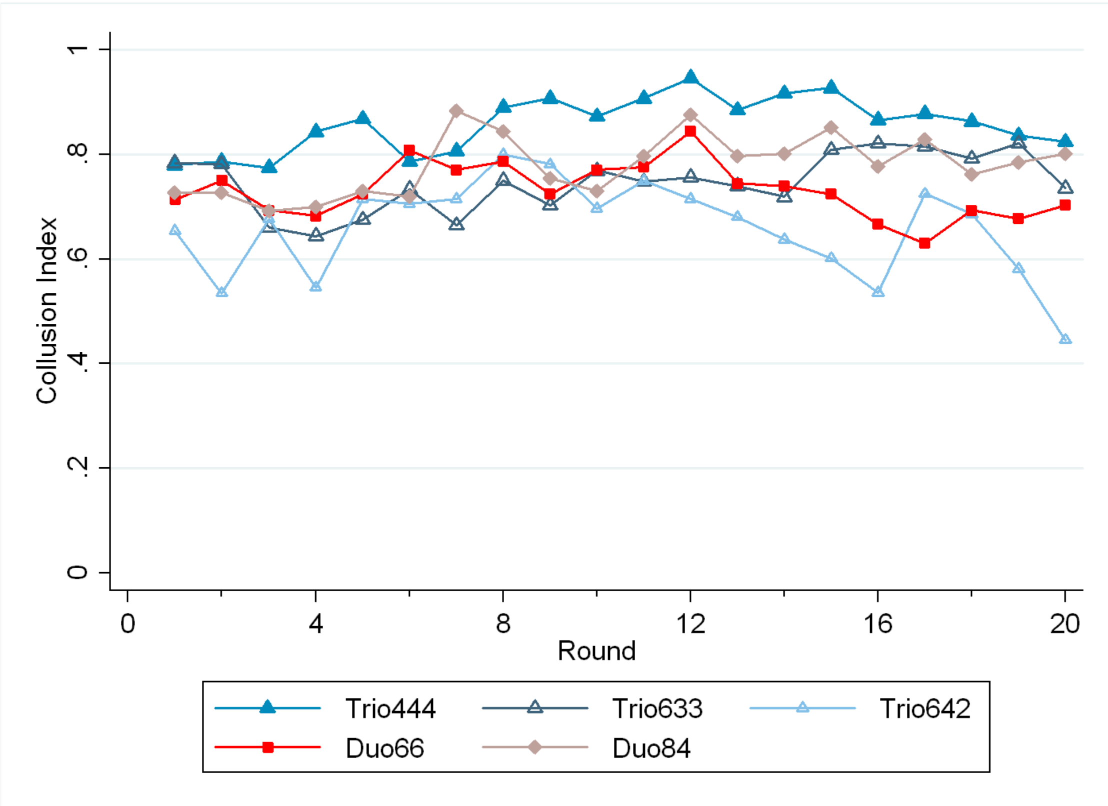


Figure 2: Average collusion index per round (across all groups).

Figure 2 again suggests that Trio444 is the most collusive while Trio642 is the least collusive treatment. Table 9 reveals that this measure yields similar conclusions to the extent of full collusion that we used in the previous subsection. Two comparisons that were significant when looking at full collusion no longer are when we focus on the collusion index. On the other hand, this measure does indicates that the heterogeneity-increasing merger (measured by the HHI) from Trio642 to Duo84 also increases the extent of collusion.

Treatment	Average	Median	Trio633	Trio642	Duo66	Duo84
Trio444	85.8%	99.6%	$\approx$	$>^{**}$	$>^{*}$	$>^{*}$
Trio633	74.6%	88.5%		$\approx$	$\approx$	$\approx$
Trio642	65.9%	64.2%			$\approx$	$<^{+}$
Duo66	73.1%	86.0%				$\approx$
Duo84	77.9%	84.1%				

Entries in the right-hand panel indicate whether the row treatment yields a collusion index that is significantly lower (<), significantly higher (>) or that does not differ significantly ($\approx$) from the index in the column treatment. $^{+}$ significantly different at 10%; * at 5%; ** at 1% (MWU test for equality).

Table 9: Collusion index per treatment (across all rounds and groups).

Results in Table 10 are qualitatively similar to those in Table 6: a more heterogeneous market increases collusion in a market with 3 firms.

	(1)	(2)	(3)	(4)
	2 firms	3 firms	Homogeneous	Heterogeneous
heterogeneous	0.0479	-0.157*		
	(0.0984)	(0.0703)		
three firms			0.127	-0.0778
			(0.0954)	(0.0743)
constant	0.731***	0.858***	0.731***	0.779***
	(0.0784)	(0.0541)	(0.0783)	(0.0592)
Observations	640	1000	660	980

Random effects linear regression models of the collusion index of groups. Standard errors in parentheses. $^{+}$ significant at 10%; * at 5%; ** at 1%; *** at 0.1%. The regression in column (1) includes data from treatments Duo66 and Duo84, that in column (2) from Trio444, Trio633 and Trio642, that in column (3) from Duo66 and Trio444, that in column (4) from Duo84, Trio633 and Trio642.

Table 10: Regression results for collusion index.

Summing up,

Result 2. *With a uniform weighted yardstick,*

(a) the collusion index decreases if market shares become more heterogeneous with three firms;

(b) the heterogeneity of market shares is more important than the number of firms.

6.1.3 Price

So far, we have only looked at the effect on market structure on the extent of collusion. Arguably, however, at the end of the day a regulator is more interested in the price for consumers that ultimately prevails. Despite higher collusion, for example, a market structure may still be preferable if it leads to lower competitive prices that more than outweigh the adverse effects on collusion.

The average price in each round is depicted in Figure 3. In most cases there is no clear time trend, except for Trio642 where prices seem to decrease over time. This is the most heterogeneous market setting.

Table 11 provides summary statistics. Average prices are rather high, and come closest to the collusive outcome in Trio444. From the table, we see that most pairwise comparisons do not yield significant differences. Trio444 does lead to significantly higher prices than Trio642 though (hence, in this case heterogeneity leads to lower prices), while Trio642 leads to significantly lower prices than Duo84.

Treatment	Average	Median	Trio633	Trio642	Duo66	Duo84
Trio444	11.00	12.00	$\approx$	$>^*$	$\approx$	$\approx$
Trio633	10.04	11.13		$\approx$	$\approx$	$\approx$
Trio642	9.48	9.38			$\approx$	$<^*$
Duo66	10.32	11.21				$\approx$
Duo84	10.76	11.31				

Entries in the right-hand panel indicate whether the row treatment yields prices that are significantly lower ($<$), significantly higher ($>$) or that do not differ significantly ($\approx$) from the column treatment. * significantly different at 5% (MWU test for equality).

Table 11: Market price per treatment (across all rounds and groups).

Table 6.1.3 shows that heterogeneity significantly decreases prices with 3 firms, while an increase in the number of firms leads to (weakly) significantly lower prices in hetero-

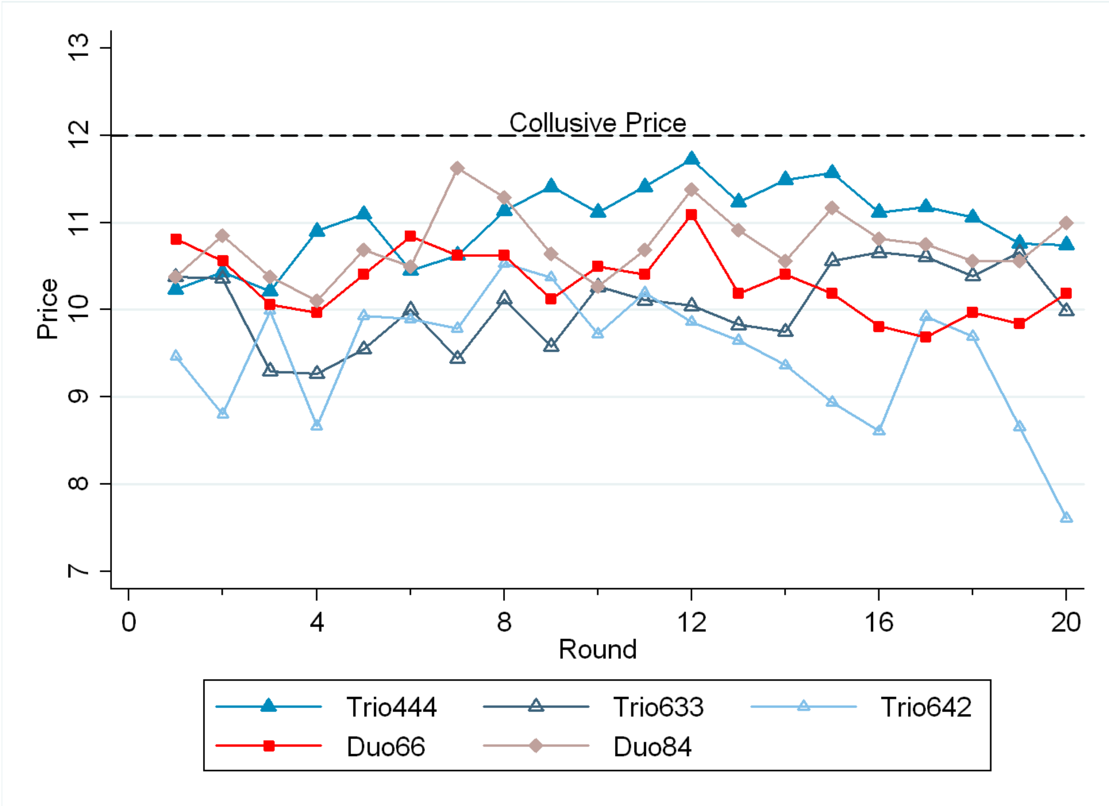


Figure 3: Average market price per round (across all groups).

geneous markets, but not in homogeneous ones. Surprisingly, in the latter case prices even increase when number of firms increases, but this result is not significant.

	(1)	(2)	(3)	(4)
	2 firms	3 firms	Homogeneous	Heterogeneous
heterogeneous	0.441	-1.242**		
	(0.658)	(0.597)		
three firms			0.680	-1.002^{+}
			(0.712)	(0.532)
constant	10.32***	11.00***	10.32***	10.76***
	(0.520)	(0.484)	(0.520)	(0.401)
Observations	640	1000	660	980

Random-effects linear regression models of group's market prices. Standard errors in parentheses. $^{+}$significant at 10%; *at 5%; **at 1%; ***at 0.1%. The regression in column (1) includes data from treatments Duo66 and Duo84, that in column (2) from Trio444, Trio633 and Trio642, that in column (3) from Duo66 and Trio444, that in column (4) from Duo84, Trio633 and Trio642.

Summing up, we have

Result 3. *With a uniform weighted yardstick, prices*

(a) decrease if market shares become more heterogeneous with three firms;

(b) increase if the number of firms decreases and market shares are heterogeneous.

The average cost level set if the group is not fully colluding, is provided in Table 12. Obviously, the average individual cost levels are not as low as the competitive cost levels. However, the cost levels are lower for smaller firms than for larger firms, which is more or less in line with theory that smaller firms can gain more by decreasing their cost level.

Treatment	Firm Size of Player		
	Small	Intermediate	Large
Trio633	6.88		8.69
Trio642	7.21	7.86	8.89
Duo84	9.44		9.91

Table 12: Average cost levels at the individual level (only rounds are included in which not all firms in a group set the fully collusive cost level of 12)

Regression results in Table 13 indicate that large firms set significantly higher cost levels but only in the 3-firm treatments. The intermediate firm in Trio642 does not set significantly higher cost levels than the small firm, nor are its cost levels smaller than that of the large firm.[4]

6.2 Results Yardstick Design

6.2.1 Collusion

In this section, we discuss our results with respect to the choice of yardstick. Again, we look at the rate of full collusion, the collusion index, and prices.

From Figure 4 it appears that the rate of collusion increases over time in the Discriminatory context and, to a lesser extent, in the Weighted treatment.

In Table 14, we see that Best Practice yields collusion rates that are significantly higher than in any other treatment, which is in line with the Theoretical Result 2.

[4] A t-test results in a significance level of .1241.

	Trio633	Trio642	Duo84
large	1.827***	1.531*	1.116
	(0.482)	(0.778)	(0.854)
intermediate		0.465	
		(0.826)	
constant	6.526***	7.286***	9.059***
	(0.346)	(0.635)	(0.664)
Observations	402	669	362

Random-effects linear regression models of the cost level set at individual level. Standard errors in parentheses. Only rounds are included in which not all firms in a group set the fully collusive cost level of 12. + significant at 10%; * at 5%; ** at 1%; *** at 0.1%.

Table 13: Regression results for cost levels.

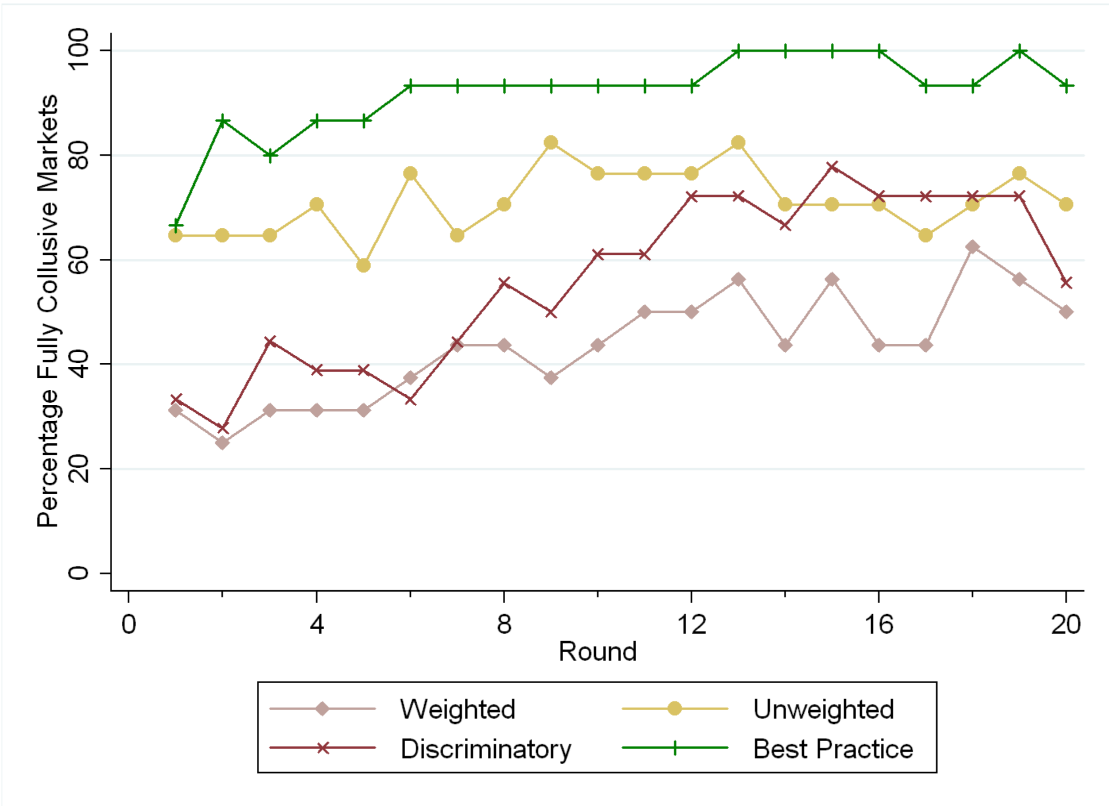


Figure 4: Incidence of full collusion per round (across all groups).

Summary statistics on the percentage of firms setting the fully collusive cost level in rounds that a group is not fully collusive, are presented in Table 15. With a weighted or

Treatment	Average	Median	Unweighted	Discriminatory	Best Practice
Weighted	43.4%	32.5%	$<^{*}$	$\approx$	$<^{***}$
Unweighted	71.2%	80.0%		$>^{*}$	$<^{+}$
Discriminatory	56.1%	70.0%			$<^{***}$
Best Practice	92.0%	100.0%			

Entries in the right-hand panel indicate whether the row treatment yields collusion rates that are significantly lower ($<$), significantly higher ($>$) or that do not differ significantly ($\approx$) from the rates in the column treatment. $^{+}$ significantly different at 10%; * at 5%; ** at 1%; *** at 0.1% (MWU test for equality).

Table 14: Incidence of full collusion per treatment (across all rounds and groups).

an unweighted yardstick the large firms are more collusive than the small firms, while it is the other way around with the discriminatory or Best Practice yardstick.

Treatment	Firm Size of Player	
	Small	Large
Weighted	27.3%	16.2%
Unweighted	5.2%	12.9%
Discriminatory	22.0%	11.9%
Best Practice	35.7%	19.0%

Table 15: Average percentage of players setting the fully collusive cost level of 12 (only rounds are included in which not all firms in a group set the fully collusive cost level of 12)

The differences are small, however. Our logit regressions in Table 16 confirm that there is no firm-size effect because all coefficients for the large firms are insignificant.

	Weighted	Unweighted	Discriminatory	Best Practice
large	-0.0164	0.639	-0.439	-1.746
	(0.689)	(0.931)	(0.697)	(2.389)
constant	-2.093***	-3.301***	-2.178***	-1.531
	(0.483)	(0.763)	(0.503)	(1.593)
lnsig2u				
constant	0.651	0.540	0.717	2.174
	(0.569)	(0.827)	(0.562)	(1.386)
Observations	362	196	316	48

Random-effects binomial logit models for fully collusive markets. Standard errors in parentheses. Only rounds are included in which not all firms in a group set the fully collusive cost level of 12. $^{+}$ significant at 10%; * at 5%; ** at 1%; *** at 0.1%.

Table 16: Regression results for incidence of full collusion at the individual level.

6.2.2 Collusion Index

We now consider the collusion index. Since we are now using different yardsticks, (47) changes to

$$\text{collusion index} \equiv \frac{\text{price} - p^{y*}}{12 - p^{y*}}. \tag{48}$$

where $y \in \{\text{UW, UU, D, BP}\}$.

From Figure 5, the collusion index is roughly comparable for all treatments, except for Best Practice. This is confirmed in the statistical analysis in Table 17.

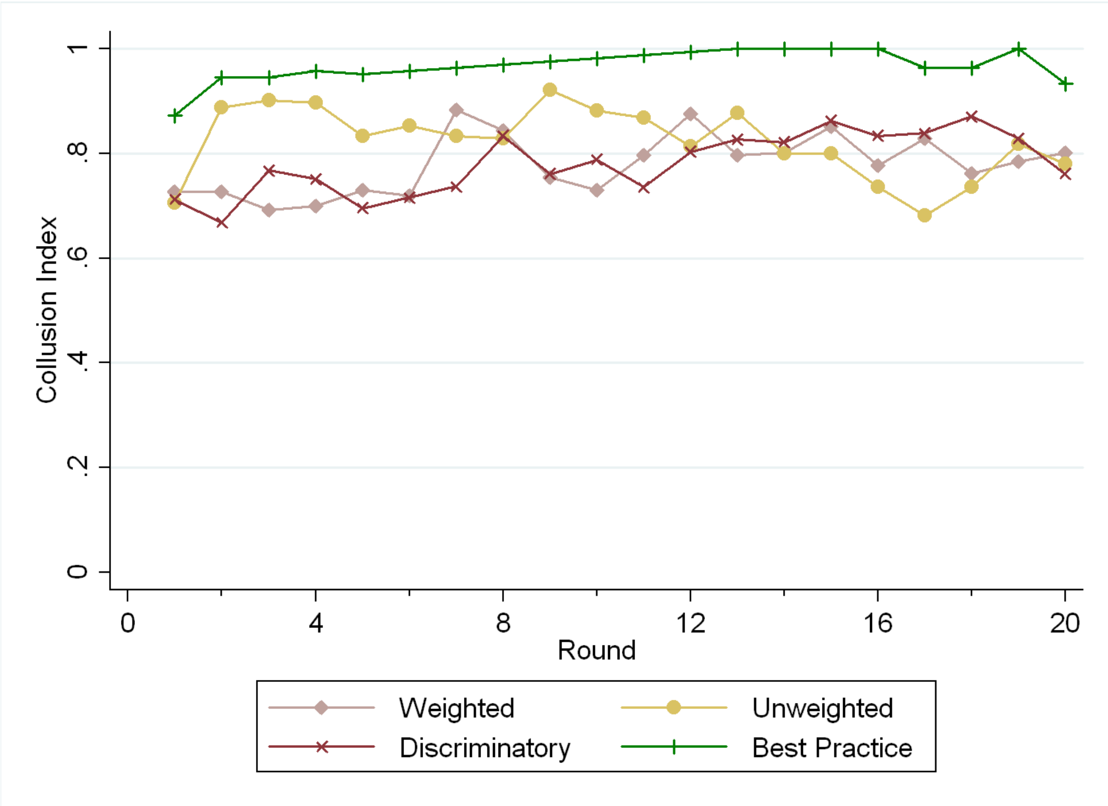


Figure 5: Average collusion index per round (across all groups).

This story also emerges from Table 17. Best Practice results in significantly higher collusion indexes, while the other three treatments do not differ significantly from each other.

Treatment	Average	Median	Unweighted	Discriminatory	Best Practice
Weighted	77.9%	84.1%	$\approx$	$\approx$	$<^{***}$
Unweighted	82.3%	92.5%		$\approx$	$<^{*}$
Discriminatory	78.0%	90.5%			$<^{***}$
Best Practice	96.8%	100.0%			

Entries in the right-hand panel indicate whether the row treatment yields a collusion index that is significantly lower (<), significantly higher (>) or that does not differ significantly ($\approx$) from the index in the column treatment. * significantly different at 5%; *** at 0.1% (MWU test for equality).

Table 17: Collusion index per treatment (across all rounds and groups).

6.2.3 Price

Because firms charge different prices with a Discriminatory yardstick, the weighted average of these prices is calculated: $\frac{2}{3}$ of the price the large firm charges plus $\frac{1}{3}$ of the price the small firm charges, i.e. $\frac{2}{3}$ of the cost level of the small firm plus $\frac{1}{3}$ of the cost level of the large firm.

Figure 6 presents the average prices over time. Best Practice results in the highest, that are close to the fully collusive price. On the other hand, a discriminatory yardstick yields much lower prices. This is confirmed in Table 18.

Treatment	Average	Median	Unweighted	Discriminatory	Best Practice
Weighted	10.76	11.31	$\approx$	$\approx$	$<^{**}$
Unweighted	10.99	11.73		$>^{*}$	$<^{+}$
Discriminatory	9.80	10.96			$<^{***}$
Best Practice	11.65	12.00			

Entries in the right-hand panel indicate whether the row treatment yields average prices that are significantly lower (<), significantly higher (>) or that do not differ significantly ($\approx$) from the average prices in the column treatment. $^{+}$ significantly different at 10%; * at 5%; ** at 1%; *** at 0.1% (MWU test for equality).

Table 18: Market price per treatment (across all rounds and groups).

Result 4. *Average prices under the best-practice treatment are significantly higher than in any other treatment. Average prices in the Discriminatory treatment are significantly lower than those in the Unweighted treatment.*

We see in Table 19 that larger firms set on average a higher cost level than smaller firms with a weighted yardstick. The differences for other yardstick designs are small,

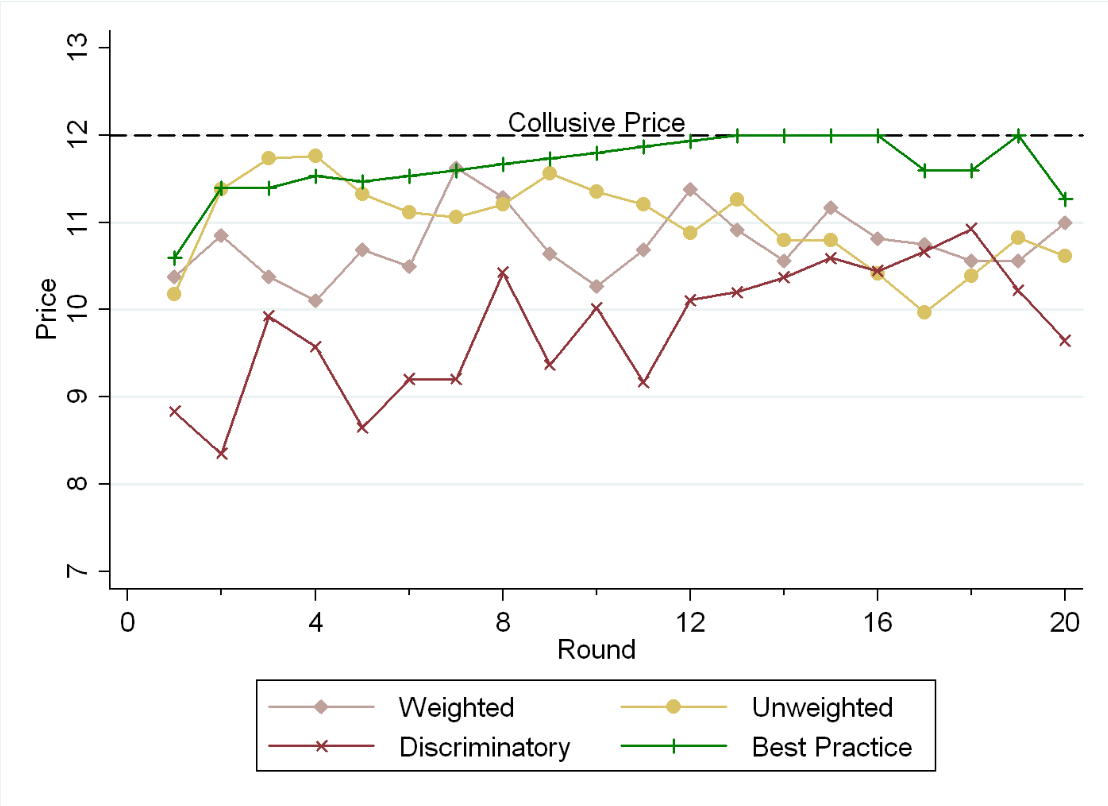


Figure 6: Average market price per round (across all groups).

which seem to be explained by the incentive power which does not depend on firm size in those yardstick designs. From Table 19 we also see that the average cost level set is

Treatment	Firm Size of Player	
	Small	Large
Weighted	9.44	9.91
Unweighted	8.44	8.74
Discriminatory	7.42	6.52
Best Practice	8.48	9.23

Table 19: Average cost levels at the individual level (only rounds are included in which not all firms in a group set the fully collusive cost level of 12)

higher than the competitive cost level. From theory we know that the incentives to lower cost levels are higher for small than for large firms with a weighted yardstick. This is reflected in the lower average cost level of small firms than of large firms, with a weighted yardstick.

Table 20 shows that large firms do not significantly set different cost levels than small firms for all yardstick designs.

	Weighted	Unweighted	Discriminatory	Best Practice
large	1.116	0.0471	-0.603	0.538
	(0.854)	(0.992)	(1.250)	(1.755)
constant	9.059***	8.608***	7.302***	8.672***
	(0.664)	(0.681)	(0.903)	(1.494)
Observations	362	196	316	48

Random-effects linear regression models of the cost level set at individual level. Standard errors in parentheses. Only rounds are included in which not all firms in a group set the fully collusive cost level of 12. $^{+}$ significant at 10%; * at 5%; ** at 1%; *** at 0.1%.

Table 20: Regression results for cost levels.

7 Conclusion

In this paper we analysed the behaviour of economic agents subject to yardstick competition by conducting an economic experiment. Economic experiments are in particular valuable when there is no empirical data to test theoretical hypotheses as is the case with yardstick competition. This method enabled us to analyse behaviour of economic agents under fully controlled circumstances.

On the basis of a simple theoretical model we found that the behaviour of economic agents under yardstick competition depends on both the industry structure and the design of the yardstick. In the absence of collusive behaviour, an increase in the number of firms lowers the average price. This is due to the fact that with fewer firms the incentive power is also lower. Moreover, if the size distribution of firms is more unequal, the average price is higher as the incentive power is lower on average. Regarding the design of the yardstick, the theoretical prediction is that the competitive price is lowest in case of a best-practice or discriminatory yardstick: the incentive power is the highest in these cases. With a uniform yardstick (both weighted and unweighted) the incentives to improve efficiency are weaker, resulting in higher average prices. Finally, with the size distribution of firms unequal, the weighted uniform yardstick results in higher competitive prices than the unweighted uniform yardstick.

From our experiment, we find that an increase in the number of heterogeneous firms reduces price. This is entirely caused by the increase in incentive power: the extent of collusion does not change. An increase in the number of homogeneous firms also does not affect the yardstick, but we find, contrary to our expectation, less collusive behavior when the number of homogeneous firms is lower. We also find less collusion when the degree of heterogeneity with 3 firms increases. The latter effect appears to be stronger than the effect of the number of firms: an increase in heterogeneity together with a decrease in the number of firms reduces the extent of collusion.

Regarding yardstick design, we find that best-practice yields the highest average price and the highest extent of collusion. In this variant of yardstick competition, firms do not have any incentive to deviate from a collusive agreement as they will immediatedly be punished by lower tariffs. The discriminatory design results in the lowest average price: the incentive power in this design is high, while the extent of collusion is much lower than in the case of best-practice. The weighted uniform yardstick yields average prices that are comparable to the unweighted yardstick, while the extent of collusion is also similar.

Summing up, we find, first, that the heterogeneity of the industry has a strong effect on collusion, much more so than the number of firms, and, second, that the discriminatory yardstick yields the lowest average prices while the best-practice yardstick yields the highest average prices. These conclusions are relevant for the debate on the optimal structure of the industry: changing it towards less heterogeneity might lead to higher tariffs for network users. Of course, these conclusions are conditional on the set up of the experiment. Further research with different setups of the experiment are needed to validate our conclusions.

A Regression Model

A.1 Market Structure

We are interested in the general effect market share heterogeneity has on collusion and market prices. Furthermore, we are also interested in the general effect on collusion and market prices of the number of firms active on the market. Therefore, we investigate these effects into more detail by estimating regression models.

Let y_{rg} be the price in round $r \in \{1, 2, \ldots, 20\}$ of group g. To estimate the effect of market share heterogeneity for two firms on prices, e.g., we only use the observations of treatments Duo66 and Duo84. We then estimate the following random-effects linear regression model:

$$y_{rg} = \beta_0 + \beta_1 \text{heterogeneous}_g + u_g + \epsilon_{rg} \tag{A1}$$

where β_0 and β_1 are coefficients to be estimated, u_g is the random intercept for all observations belonging to group g, and ϵ_{rg} is an independently distributed error term. Finally, indicator heterogeneous$_g$ is a dummy that equals 1 if group g had heterogeneous market shares (Duo84) and 0 otherwise (Duo66). Results are provided in column (1) of Table 6.1.3. The indicator heterogeneous$_g$ is defined similarly if we want to estimate the effect of market share heterogeneity for three firms. The indicator equals 1 if group g had heterogeneous market shares (Trio633 and Trio642) and 0 otherwise (Trio444). Results are provided in column (2) of Table 6.1.3.

To estimate the effect of the number of firms for homogeneous markets on prices, we use the observations of treatments Duo66 and Trio444. We then estimate the following random-effects linear regression model:

$$y_{rg} = \beta_0 + \beta_1 \text{threefirms}_g + u_g + \epsilon_{rg} \tag{A2}$$

where threefirms$_g$ is a dummy that equals 1 if group g had three firms per market (Trio444) and 0 otherwise (Duo66). Results are provided in column (3) of Table 6.1.3. The indicator threefirms$_g$ is defined similarly if we want to estimate the effect of the number of firms for heterogeneous markets. The indicator equals 1 if group g had three firms per market (Trio633 and Trio642) and 0 otherwise (Duo84). Results are provided in column (4) of Table 6.1.3.

To estimate these effects for the collusion index, let y_{rg} be the collusion index in round r of group g in (A1) and (A2). Results are provided in Table 10.

When considering collusion, let $y_{rg} = 1$ if group g was collusive in round r, and $y_{rg} = 0$ otherwise. In this case, we do not estimate (A1) but the following random-effects binomial logit model of the underlying variable y^*_{rg}, where $y_{rg} = 1$ if $y^*_{rg} > 0$ and $y_{rg} = 0$ if $y^*_{rg} \leq 0$:

$$y^*_{rg} = \beta_0 + \beta_1 \text{heterogeneous}_g + u_g + \epsilon_{rg}. \tag{A3}$$

Similarly, in (A2) we replace y_{rg} with y^*_{rg}. Results are provided in Table 6.

In all cases, the significance level of β_1 which are obtained using two-sided z-tests is reported in the tables of section 6.1.

A.2 Individual Level

Let y_{ri} be the cost level set in round $r \in \{1, 2, \ldots, 20\}$ by individual i. To estimate the effect of firm size on cost level, we estimate the following random-effects linear regression model:

$$y_{ri} = \beta_0 + \beta_1 \text{intermediate}_i + \beta_2 \text{large}_i + u_i + \epsilon_{ri} \tag{A4}$$

where β_0, β_1 and β_2 are coefficients to be estimated, u_i is the random intercept for all observations belonging to individual i, and ϵ_{ri} is an independently distributed error term. Finally, indicator intermediate$_i$ is a dummy that equals 1 for player 2 in Trio642, and 0 otherwise. Indicator large$_i$ is a dummy that equals 1 for player 1 in Trio633, Trio642, Duo84/Weighted, Unweighted, Discriminatory and Best Practice; and 0 otherwise.

B Instructions Trio633

A

Introduction

You are going to participate in an experiment in economics. We will first read the instructions aloud. Then you will have time to read them on your own. The instructions are identical for all participants. After reading, there is the possibility to ask questions individually. The experiment is expected to last for approximately 90 minutes. Please refrain from talking during the entire experiment.

You will play with two other players, chosen at random. Together, you and those two other players form a group. You will never learn who the other players are. The experiment lasts for at least 20 rounds. In each round, you will play with the same two players. Before the experiment starts, we randomly determine whether you are player 1, player 2 or player 3 in your group.

In this experiment you can earn points. The number of points you earn depends on the decisions made by you and those made by the other players in your group.

Instructions

In the experiment, each player represents a company. Each player owns a number of production units. In each round, each player has to choose one cost level for all production units that he or she owns. Player 1 owns 2 production units. Player 2 owns 1 production unit. Player 3 owns 1 production unit. At the beginning of the experiment, each player starts with 40 points for each production unit that he or she owns. Player 1 will thus receive 80 points, player 2 receives 40 points and player 3 receives 40 points. In each round, the number of points you earn consists of two components: **profit** and **managerial benefit**. At the end of each round, the points that you earned in that round will be added to your account.

After the experiment the number of points in your account will be converted to euros. Player 1 will receive €1 for every 20 points that he or she has, player 2 will receive €1 for every 10 points, and player 3 will receive €1 for every 10 points.

Each round consists of three steps. These steps are the same in every round.

Step 1: communication

A chat box will appear on your screen. You can discuss anything you want with the other players in your group. However, you are not allowed to identify yourself by name, gender, appearance, nationality, or in any other way. If you do, you will not receive any payment after the experiment. You are only allowed to communicate in English.

You have a limited amount of time to chat. A timer in the top right corner of the screen will inform you of the amount of time you have left. If you prefer not to chat any more, you can leave the chat by pressing the “Leave Chat” button. Once you have left the chat, you cannot return in that round. Once two persons have left the chat, the chat will end automatically.

Step 2: choice of cost level

Each player chooses one cost level for all the production units that he or she owns. You can choose your cost level from the following possibilities:

$$1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20.$$

The cost level you choose will influence the profits in that round for you and the other players. It will also influence your managerial benefit.

Each production unit produces one unit of output. The price you will receive per unit of output equals the average cost level of all production units on the market.

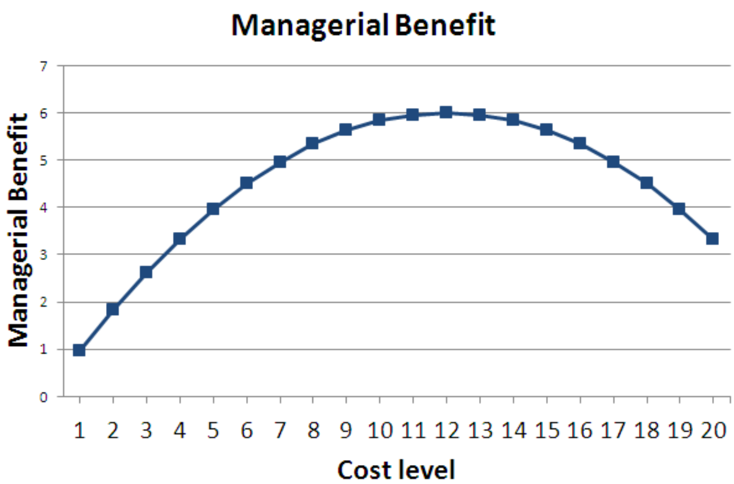
Example. Suppose that player 1 chooses a cost level of 10, player 2 chooses a cost level of 5 and player 3 chooses a cost level of 7. Keeping in mind that player 1 owns 2 production units, player 2 owns 1 production unit, and player 3 owns 1 production unit, the price for each unit of output is then

$$\frac{2 \times 10 + 1 \times 5 + 1 \times 7}{2 + 1 + 1} = \frac{20 + 5 + 7}{4} = \frac{32}{4} = 8. \qquad \blacksquare$$

The profit you earn on each unit of output equals the price minus your cost level. Thus,

$$\text{your profit} = \text{your number of production units} \times (\text{price} - \text{cost level}).$$

For each of your production units you also receive a managerial benefit. This graph shows how your managerial benefit per production unit depends on your cost level:



The number of points you receive in a round is equal to your profit plus your managerial benefit.

If you prefer, you can also calculate your profit and managerial benefit using a profit calculator that we will provide on screen during the experiment. Alternatively, you can find your profit and your managerial benefit in a table that we provide. These tables are added to these instructions. Please put these tables in front of you now.

Each table reads as follows. Rows represent the possible cost levels you can choose. Columns represent the average cost level per production unit of the other two players. Where a row and a column intersect, you can find your profit. Your managerial benefit is indicated in the last column.

Example. We consider a case in which player 1 chooses a cost level of 10, player 2 chooses a cost level of 5 and player 3 chooses a cost level of 7. As player 1 owns 2 production units and players 2 and 3 each own 1 production unit, the price per unit of output equals $\frac{2\times10+1\times5+1\times7}{2+1+1} = 8$. Profits, managerial benefits, and number of points for all players can be found as follows.

- Consider player 1. Its cost level is 10. The average cost level of the production units owned by players 2 and 3 is $\frac{1\times5+1\times7}{1+1} = \frac{5+7}{2} = 6$. Player 1's profit can be found in Table 1, in the row marked 10, and the column marked 6. You can see that player 1 receives a profit of -4.00 points. Note that player 1 can also calculate this directly. As noted, the price per unit of output in this case equals 8. As player 1 owns two production units, profit is $2 \times (8 - 10) = -4$.

  At the end of the row marked 10, you can see that player 1 receives a managerial benefit of 11.67 points. This can also roughly be seen from the graph. With cost level 10, managerial benefit per production unit is roughly 5.8, which implies total managerial benefit of $2 \times 5.8 \approx 11.6$.

  In total, player 1 thus receives $-4 + 11.67 = 7.67$ points.

- Consider player 2. Its cost level is 5. The average cost level of the production units owned by players 1 and 3 is $\frac{2\times10+1\times7}{2+1} = \frac{27}{3} = 9$. Player 2's profit can be found in Table 2 (the row marked 5, the column marked 9) to equal 3.00 points. Alternatively, note that price per unit in this case equals 8. As player 2 owns one production unit, profit is $8 - 5 = 3$.

  The managerial benefit of player 2 can be found at the end of the row marked 5 to equal 3.96 points. This can also roughly be seen from the graph.

  In total, player 2 thus receives $3.00 + 3.96 = 6.96$ points.

- Consider player 3. Its cost level is 7. The average cost level of the production units owned by players 1 and 2 is $\frac{2\times10+1\times5}{2+1} = \frac{20+5}{3} = 8.33$. If it were 8, player 3's profit could be found in Table 3 (row marked 7, column marked 8) to equal 0.75. If it were 9, player 3's profit could be found in Table 3 (row marked 7, column marked 9) to equal 1.50. As the average cost level of other production units is 8.33, player 3's profit is as in column 8 plus 1/3 times the difference between both columns: $0.75 + \frac{1}{3} \times (1.50 - 0.75) = 1.00$ points.

Alternatively, price per unit equals 8. As player 3 owns one production unit, profit is $8 - 7 = 1$.

The managerial benefit of player 3 can be found at the end of the row marked 7 to equal 4.96 points. This can also roughly be seen from the graph.

In total, player 3 thus receives $1.00 + 4.96 = 5.96$ points.

Step 3: summary
After all players have made their decision, you will receive the following information: the cost levels chosen by the other players, the price for each unit of output, your profit, your managerial benefit, and the current state of your account. Throughout the experiment, there will also be a box on your screen where you can observe the decisions made by you and the other players in each previous round.

End of experiment
You will at least play 20 rounds. From round 20 onwards, the experiment ends with a 20% probability at the end of each round. With a probability of 80%, a new round starts. You receive a message on your screen if no further round will take place.

At the end of the experiment the number of points in your account will be converted to euros. Before you can collect your payment in private, you have to hand in the instructions.

After the experiment, please do not discuss the content of the experiment with anyone, including people who did not participate.

Please refrain from talking throughout the experiment.

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